

Annex III

BEST AVAILABLE TECHNIQUES FOR CONTROLLING EMISSIONS OF HEAVY METALS AND  
THEIR COMPOUNDS FROM THE SOURCE CATEGORIES LISTED IN ANNEX II

I. INTRODUCTION

1. This annex aims to provide Parties with guidance on identifying best available techniques for stationary sources to enable them to meet the obligations of the Protocol.

2. "Best available techniques" (BAT) means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and their impact on the environment as a whole:

- 'Techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- 'Available' techniques means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the territory of the Party in question, as long as they are reasonably accessible to the operator;
- 'Best' means most effective in achieving a high general level of protection of the environment as a whole.

In determining the best available techniques, special consideration should be given, generally or in specific cases, to the factors below, bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention:

- The use of low-waste technology;
- The use of less hazardous substances;
- The furthering of recovery and recycling of substances generated and used in the process and of waste;
- Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
- Technological advances and changes in scientific knowledge and understanding;
- The nature, effects and volume of the emissions concerned;

- The commissioning dates for new or existing installations;
- The time needed to introduce the best available technique;
- The consumption and nature of raw materials (including water) used in the process and its energy efficiency;
- The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
- The need to prevent accidents and to minimize their consequences for the environment.

The concept of best available techniques is not aimed at the prescription of any specific technique or technology, but at taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions.

3. The information regarding emission control performance and costs is based on official documentation of the Executive Body and its subsidiary bodies, in particular documents received and reviewed by the Task Force on Heavy Metal Emissions and the Ad Hoc Preparatory Working Group on Heavy Metals. Furthermore, other international information on best available techniques for emission control has been taken into consideration (e.g. the European Community's technical notes on BAT, the PARCOM recommendations for BAT, and information provided directly by experts).

4. Experience with new products and new plants incorporating low-emission techniques, as well as with the retrofitting of existing plants, is growing continuously; this annex may, therefore, need amending and updating.

5. The annex lists a number of measures spanning a range of costs and efficiencies. The choice of measures for any particular case will depend on, and may be limited by, a number of factors, such as economic circumstances, technological infrastructure, any existing emission control device, safety, energy consumption and whether the source is a new or existing one.

6. This annex takes into account the emissions of cadmium, lead and mercury and their compounds, in solid (particle-bound) and/or gaseous form. Speciation of these compounds is, in general, not considered here. Nevertheless, the efficiency of emission control devices with regard to the physical properties of the heavy metal, especially in the case of mercury, has been taken into account.

7. Emission values expressed as mg/m<sup>3</sup> refer to standard conditions (volume at 273.15 K, 101.3 kPa, dry gas) not corrected for oxygen content unless otherwise specified, and are calculated in accordance with draft CEN (Comité européen de normalisation) and, in some cases, national sampling and monitoring techniques.

## II. GENERAL OPTIONS FOR REDUCING EMISSIONS OF HEAVY METALS AND THEIR COMPOUNDS

8. There are several possibilities for controlling or preventing heavy metal emissions. Emission reduction measures focus on add-on technologies and process modifications (including maintenance and operating control). The following measures, which may be implemented depending on the wider technical and/or economic conditions, are available:

(a) Application of low-emission process technologies, in particular in new installations;

(b) Off-gas cleaning (secondary reduction measures) with filters, scrubbers, absorbers, etc.;

(c) Change or preparation of raw materials, fuels and/or other feed materials (e.g. use of raw materials with low heavy metal content);

(d) Best management practices such as good housekeeping, preventive maintenance programmes, or primary measures such as the enclosure of dust-creating units;

(e) Appropriate environmental management techniques for the use and disposal of certain products containing Cd, Pb, and/or Hg.

9. It is necessary to monitor abatement procedures to ensure that appropriate control measures and practices are properly implemented and achieve an effective emission reduction. Monitoring abatement procedures will include:

(a) Developing an inventory of those reduction measures identified above that have already been implemented;

(b) Comparing actual reductions in Cd, Pb and Hg emissions with the objectives of the Protocol;

(c) Characterizing quantified emissions of Cd, Pb and Hg from relevant sources with appropriate techniques;

(d) Regulatory authorities periodically auditing abatement measures to ensure their continued efficient operation.

10. Emission reduction measures should be cost-efficient. Cost-efficient strategy considerations should be based on total costs per year per unit abated (including capital and operating costs). Emission reduction costs

should also be considered with respect to the overall process.

### III. CONTROL TECHNIQUES

11. The major categories of available control techniques for Cd, Pb and Hg emission abatement are primary measures such as raw material and/or fuel substitution and low-emission process technologies, and secondary measures such as fugitive emission control and off-gas cleaning. Sector-specific techniques are specified in chapter IV.

12. The data on efficiency are derived from operating experience and are considered to reflect the capabilities of current installations. The overall efficiency of flue gas and fugitive emission reductions depends to a great extent on the evacuation performance of the gas and dust collectors (e.g. suction hoods). Capture/collection efficiencies of over 99% have been demonstrated. In particular, cases experience has shown that control measures are able to reduce overall emissions by 90% or more.

13. In the case of particle-bound emissions of Cd, Pb and Hg, the metals can be captured by dust-cleaning devices. Typical dust concentrations after gas cleaning with selected techniques are given in table 1. Most of these measures have generally been applied across sectors. The minimum expected performance of selected techniques for capturing gaseous mercury is outlined in table 2. The application of these measures depends on the specific processes and is most relevant if concentrations of mercury in the flue gas are high.

Table 1: Performance of dust-cleaning devices expressed as hourly average dust concentrations

Dust concentrations after cleaning (mg/m <sup>3</sup> )	
Fabric filters	< 10
Fabric filters, membrane type	< 1
Dry electrostatic precipitators	< 50
Wet electrostatic precipitators	< 50
High-efficiency scrubbers	< 50

Note: Medium- and low-pressure scrubbers and cyclones generally show lower dust removal efficiencies.

Table 2: Minimum expected performance of mercury separators expressed as hourly average mercury concentrations

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	Mercury content after cleaning (mg/m <sup>3</sup> )
Selenium filter	< 0.01
Selenium scrubber	< 0.2
Carbon filter	< 0.01
Carbon injection + dust separator	< 0.05
Odda Norzink chloride process	< 0.1
Lead sulphide process	< 0.05
Bolkem (Thiosulphate) process	< 0.1

14. Care should be taken to ensure that these control techniques do not create other environmental problems. The choice of a specific process because of its low emission into the air should be avoided if it worsens the total environmental impact of the heavy metals' discharge, e.g. due to more water pollution from liquid effluents. The fate of captured dust resulting from improved gas cleaning must also be taken into consideration. A negative environmental impact from the handling of such wastes will reduce the gain from lower process dust and fume emissions into the air.

15. Emission reduction measures can focus on process techniques as well as on off-gas cleaning. The two are not independent of each other; the choice of a specific process might exclude some gas-cleaning methods.

16. The choice of a control technique will depend on such parameters as the pollutant concentration and/or speciation in the raw gas, the gas volume flow, the gas temperature, and others. Therefore, the fields of application may overlap; in that case, the most appropriate technique must be selected according to case-specific conditions.

17. Adequate measures to reduce stack gas emissions in various sectors are described below. Fugitive emissions have to be taken into account. Dust emission control associated with the discharging, handling, and stockpiling of raw materials or by-products, although not relevant to long-range transport, may be important for the local environment. The emissions can be reduced by moving these activities to completely enclosed buildings, which may be equipped with ventilation and dedusting facilities, spray systems or other suitable controls. When stockpiling in unroofed areas, the material surface should be otherwise protected against wind entrainment. Stockpiling areas and roads should be kept clean.

18. The investment/cost figures listed in the tables have been collected from various sources and are highly case-specific. They are expressed in 1990 US\$ (US\$ 1 (1990) = ECU 0.8 (1990)). They depend on such factors as plant capacity, removal efficiency and raw gas concentration, type of technology, and the choice of new installations as opposed to retrofitting.

#### IV. SECTORS

19. This chapter contains a table per relevant sector with the main emission sources, control measures based on the best available techniques, their specific reduction efficiency and the related costs, where available. Unless stated otherwise, the reduction efficiencies in the tables refer to direct stack gas emissions.

##### Combustion of fossil fuels in utility and industrial boilers (annex II, category 1)

20. The combustion of coal in utility and industrial boilers is a major source of anthropogenic mercury emissions. The heavy metal content is normally several orders of magnitude higher in coal than in oil or natural gas.

21. Improved energy conversion efficiency and energy conservation measures will result in a decline in the emissions of heavy metals because of reduced fuel requirements. Combusting natural gas or alternative fuels with a low heavy metal content instead of coal would also result in a significant reduction in heavy metal emissions such as mercury. Integrated gasification combined-cycle (IGCC) power plant technology is a new plant technology with a low-emission potential.

22. With the exception of mercury, heavy metals are emitted in solid form in association with fly-ash particles. Different coal combustion technologies show different magnitudes of fly-ash generation: grate-firing boilers 20-40%; fluidized-bed combustion 15%; dry bottom boilers (pulverized coal combustion) 70-100% of total ash. The heavy metal content in the small particle size fraction of the fly-ash has been found to be higher.

23. Beneficiation, e.g. "washing" or "bio-treatment", of coal reduces the heavy metal content associated with the inorganic matter in the coal. However, the degree of heavy metal removal with this technology varies widely.

24. A total dust removal of more than 99.5% can be obtained with electrostatic precipitators (ESP) or fabric filters (FF), achieving dust concentrations of about 20 mg/m<sup>3</sup> in many cases. With the exception of mercury, heavy metal emissions can be reduced by at least 90-99%, the lower figure for the more easily volatilized elements. Low filter temperature helps to reduce the gaseous mercury off-gas content.

25. The application of techniques to reduce emissions of nitrogen oxides, sulphur dioxide and particulates from the flue gas can also remove heavy

metals. Possible cross media impact should be avoided by appropriate waste water treatment.

26. Using the techniques mentioned above, mercury removal efficiencies vary extensively from plant to plant, as seen in table 3. Research is ongoing to develop mercury removal techniques, but until such techniques are available on an industrial scale, no best available technique is identified for the specific purpose of removing mercury.

Table 3: Control measures, reduction efficiencies and costs for fossil-fuel combustion emissions

Emission source	Control measure(s)	Reduction efficiency (%)	Abatement costs
Combustion of fuel oil	Switch from fuel oil to gas	Cd, Pb: 100; Hg: 70 - 80	Highly case-specific
Combustion of coal	Switch from coal to fuels with lower heavy metals emissions	Dust: 70 - 100	Highly case-specific
	ESP (cold-side)	Cd, Pb: > 90; Hg: 10 - 40	Specific investment US\$ 5-10/m <sup>3</sup> waste gas per hour (> 200,000 m <sup>3</sup> /h)
	Wet flue-gas desulphurization (FGD) <u>a/</u>	Cd, Pb: > 90; Hg: 10 - 90 <u>b/</u>	..
	Fabric filters (FF)	Cd: > 95; Pb: > 99; Hg: 10 - 60	Specific investment US\$ 8-15/m <sup>3</sup> waste gas per hour (> 200,000 m <sup>3</sup> /h)

a/ Hg removal efficiencies increase with the proportion of ionic mercury. High-dust selective catalytic reduction (SCR) installations facilitate Hg(II) formation.

b/ This is primarily for SO<sub>2</sub> reduction. Reduction in heavy metal emissions is a side benefit. (Specific investment US\$ 60-250/kW<sub>el</sub>.)

#### Primary iron and steel industry (annex II, category 2)

27. This section deals with emissions from sinter plants, pellet plants, blast furnaces, and steelworks with a basic oxygen furnace (BOF). Emissions

of Cd, Pb and Hg occur in association with particulates. The content of the heavy metals of concern in the emitted dust depends on the composition of the raw materials and the types of alloying metals added in steel-making. The most relevant emission reduction measures are outlined in table 4. Fabric filters should be used whenever possible; if conditions make this impossible, electrostatic precipitators and/or high-efficiency scrubbers may be used.

28. When using BAT in the primary iron and steel industry, the total specific emission of dust directly related to the process can be reduced to the following levels:

Sinter plants	40 - 120 g/Mg
Pellet plants	40 g/Mg
Blast furnace	35 - 50 g/Mg
BOF	35 - 70 g/Mg.

29. Purification of gases using fabric filters will reduce the dust content to less than 20 mg/m<sup>3</sup>, whereas electrostatic precipitators and scrubbers will reduce the dust content to 50 mg/m<sup>3</sup> (as an hourly average). However, there are many applications of fabric filters in the primary iron and steel industry that can achieve much lower values.

Table 4: Emission sources, control measures, dust reduction efficiencies and costs for the primary iron and steel industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
Sinter plants	Emission optimized sintering	ca. 50	..
	Scrubbers and ESP	> 90	..
	Fabric filters	> 99	..
Pellet plants	ESP + lime reactor + fabric filters	> 99	..
	Scrubbers	> 95	..
Blast furnaces	FF / ESP	> 99	ESP: 0.24-1/Mg pig-iron
Blast furnace gas cleaning	Wet scrubbers	> 99	..
	Wet ESP	> 99	..
BOF	Primary dedusting: wet separator/ESP/FF	> 99	Dry ESP: 2.25/Mg steel
	Secondary dedusting: dry ESP/FF	> 97	FF: 0.26/Mg steel
Fugitive	Closed conveyor belts,	80 - 99	..

emissions	enclosure, wetting stored feedstock, cleaning of roads		
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30. Direct reduction and direct smelting are under development and may reduce the need for sinter plants and blast furnaces in the future. The application of these technologies depends on the ore characteristics and requires the resulting product to be processed in an electric arc furnace, which should be equipped with appropriate controls.

Secondary iron and steel industry (annex II, category 3)

31. It is very important to capture all the emissions efficiently. That is possible by installing doghouses or movable hoods or by total building evacuation. The captured emissions must be cleaned. For all dust-emitting processes in the secondary iron and steel industry, dedusting in fabric filters, which reduces the dust content to less than 20 mg/m<sup>3</sup>, shall be considered as BAT. When BAT is used also for minimizing fugitive emissions, the specific dust emission (including fugitive emission directly related to the process) will not exceed the range of 0.1 to 0.35 kg/Mg steel. There are many examples of clean gas dust content below 10 mg/m<sup>3</sup> when fabric filters are used. The specific dust emission in such cases is normally below 0.1 kg/Mg.

32. For the melting of scrap, two different types of furnace are in use: open-hearth furnaces and electric arc furnaces (EAF) where open-hearth furnaces are about to be phased out.

33. The content of the heavy metals of concern in the emitted dust depends on the composition of the iron and steel scrap and the types of alloying metals added in steel-making. Measurements at EAF have shown that 95% of emitted mercury and 25% of cadmium emissions occur as vapour. The most relevant dust emission reduction measures are outlined in table 5.

Table 5: Emission sources, control measures, dust reduction efficiencies and costs for the secondary iron and steel industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
EAF	ESP FF	> 99 > 99.5	.. FF: 24/Mg steel

Iron foundries (annex II, category 4)

34. It is very important to capture all the emissions efficiently. That is

possible by installing doghouses or movable hoods or by total building evacuation. The captured emissions must be cleaned. In iron foundries, cupola furnaces, electric arc furnaces and induction furnaces are operated. Direct particulate and gaseous heavy metal emissions are especially associated with melting and sometimes, to a small extent, with pouring. Fugitive emissions arise from raw material handling, melting, pouring and fettling. The most relevant emission reduction measures are outlined in table 6 with their achievable reduction efficiencies and costs, where available. These measures can reduce dust concentrations to 20 mg/m<sup>3</sup>, or less.

35. The iron foundry industry comprises a very wide range of process sites. For existing smaller installations, the measures listed may not be BAT if they are not economically viable.

Table 6: Emission sources, control measures, dust reduction efficiencies and costs for iron foundries

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
EAF	ESP	> 99	..
	FF	> 99.5	FF: 24/Mg iron
Induction furnace	FF/dry absorption + FF	> 99	..
Cold blast cupola	Below-the-door take-off:	> 98	..
	FF		
	Above-the-door take-off:		
	FF + pre-dedusting	> 97	8-12/Mg iron
	FF + chemisorption	> 99	45/Mg iron
Hot blast cupola	FF + pre-dedusting	> 99	23/Mg iron
	Disintegrator/ venturi scrubber	> 97	..

Primary and secondary non-ferrous metal industry (annex II, categories 5 and 6)

36. This section deals with emissions and emission control of Cd, Pb and Hg in the primary and secondary production of non-ferrous metals like lead, copper, zinc, tin and nickel. Due to the large number of different raw materials used and the various processes applied, nearly all kinds of heavy metals and heavy metal compounds might be emitted from this sector. Given the heavy metals of concern in this annex, the production of copper, lead and zinc are particularly relevant.

37. Mercury ores and concentrates are initially processed by crushing, and sometimes screening. Ore beneficiation techniques are not used extensively, although flotation has been used at some facilities processing low-grade ore.

The crushed ore is then heated in either retorts, at small operations, or furnaces, at large operations, to the temperatures at which mercuric sulphide sublimates. The resulting mercury vapour is condensed in a cooling system and collected as mercury metal. Soot from the condensers and settling tanks should be removed, treated with lime and returned to the retort or furnace.

38. For efficient recovery of mercury the following techniques can be used:

- Measures to reduce dust generation during mining and stockpiling, including minimizing the size of stockpiles;
- Indirect heating of the furnace;
- Keeping the ore as dry as possible;
- Bringing the gas temperature entering the condenser to only 10 to 20°C above the dew point;
- Keeping the outlet temperature as low as possible; and
- Passing reaction gases through a post-condensation scrubber and/or a selenium filter.

Dust formation can be kept down by indirect heating, separate processing of fine grain classes of ore, and control of ore water content. Dust should be removed from the hot reaction gas before it enters the mercury condensation unit with cyclones and/or electrostatic precipitators.

39. For gold production by amalgamation, similar strategies as for mercury can be applied. Gold is also produced using techniques other than amalgamation, and these are considered to be the preferred option for new plants.

40. Non-ferrous metals are mainly produced from sulphidic ores. For technical and product quality reasons, the off-gas must go through a thorough dedusting ( $< 3 \text{ mg/m}^3$ ) and could also require additional mercury removal before being fed to an  $\text{SO}_2$  contact plant, thereby also minimizing heavy metal emissions.

41. Fabric filters should be used when appropriate. A dust content of less than  $10 \text{ mg/m}^3$  can be obtained. The dust of all pyrometallurgical production should be recycled in-plant or off-site, while protecting occupational health.

42. For primary lead production, first experiences indicate that there are interesting new direct smelting reduction technologies without sintering of the concentrates. These processes are examples of a new generation of direct autogenous lead smelting technologies which pollute less and consume less

energy.

43. Secondary lead is mainly produced from used car and truck batteries, which are dismantled before being charged to the smelting furnace. This BAT should include one melting operation in a short rotary furnace or shaft furnace. Oxy-fuel burners can reduce waste gas volume and flue dust production by 60%. Cleaning the flue-gas with fabric filters makes it possible to achieve dust concentration levels of 5 mg/m<sup>3</sup>.

44. Primary zinc production is carried out by means of roast-leach electrowin technology. Pressure leaching may be an alternative to roasting and may be considered as a BAT for new plants depending on the concentrate characteristics. Emissions from pyrometallurgical zinc production in Imperial Smelting (IS) furnaces can be minimized by using a double bell furnace top and cleaning with high-efficiency scrubbers, efficient evacuation and cleaning of gases from slag and lead casting, and thorough cleaning (< 10 mg/m<sup>3</sup>) of the CO-rich furnace off-gases.

45. To recover zinc from oxidized residues these are processed in an IS furnace. Very low-grade residues and flue dust (e.g. from the steel industry) are first treated in rotary furnaces (Waelz-furnaces) in which a high-content zinc oxide is manufactured. Metallic materials are recycled through melting in either induction furnaces or furnaces with direct or indirect heating by natural gas or liquid fuels or in vertical New Jersey retorts, in which a large variety of oxidic and metallic secondary material can be recycled. Zinc can also be recovered from lead furnace slags by a slag fuming process.

Table 7 (a): Emission sources, control measures, dust reduction efficiencies and costs for the primary non-ferrous metal industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
Fugitive emissions	Suction hoods, enclosure, etc. off-gas cleaning by FF	> 99	..
Roasting/sintering	Updraught sintering: ESP + scrubbers (prior to double contact sulphuric acid plant) + FF for tail gases	..	7 - 10/Mg H <sub>2</sub> SO <sub>4</sub>
Conventional smelting (blast furnace reduction)	Shaft furnace: closed top/ efficient evacuation of tap holes + FF, covered launders, double bell furnace top	..	..
Imperial smelting	High-efficiency scrubbing	> 95	..

	Venturi scrubbers Double bell furnace top	.. ..	.. 4/Mg metal produced
Pressure leaching	Application depends on leaching characteristics of concentrates	> 99	site-specific
Direct smelting reduction processes	Flash smelting, e.g. Kivcet, Outokumpu and Mitsubishi processes	..	..
	Bath smelting, e.g. top blown rotary converter, Ausmelt, Isasmelt, QSL and Noranda processes	Ausmelt: Pb 77, Cd 97; QSL: Pb 92, Cd 93	QSL: operating costs 60/Mg Pb

Table 7 (b): Emission sources, control measures, dust reduction efficiencies and costs for the secondary non-ferrous metal industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs, US\$)
Lead production	Short rotary furnace: suction hoods for tap holes + FF; tube condenser, oxy-fuel burner	99.9	45/Mg Pb
Zinc production	Imperial smelting	> 95	14/Mg Zn

46. In general, processes should be combined with an effective dust collecting device for both primary gases and fugitive emissions. The most relevant emission reduction measures are outlined in tables 7 (a) and (b). Dust concentrations below 5 mg/m<sup>3</sup> have been achieved in some cases using fabric filters.

#### Cement industry (annex II, category 7)

47. Cement kilns may use secondary fuels such as waste oil or waste tyres. Where waste is used, emission requirements for waste incineration processes may apply, and where hazardous waste is used, depending on the amount used in the plant, emission requirements for hazardous waste incineration processes may apply. However, this section refers to fossil fuel fired kilns.

48. Particulates are emitted at all stages of the cement production process, consisting of material handling, raw material preparation (crushers, dryers), clinker production and cement preparation. Heavy metals are brought into the cement kiln with the raw materials, fossil and waste fuels.

49. For clinker production the following kiln types are available: long wet rotary kiln, long dry rotary kiln, rotary kiln with cyclone preheater, rotary kiln with grate preheater, shaft furnace. In terms of energy demand and emission control opportunities, rotary kilns with cyclone preheaters are preferable.

50. For heat recovery purposes, rotary kiln off-gases are conducted through the preheating system and the mill dryers (where installed) before being dedusted. The collected dust is returned to the feed material.

51. Less than 0.5% of lead and cadmium entering the kiln is released in exhaust gases. The high alkali content and the scrubbing action in the kiln favour metal retention in the clinker or kiln dust.

52. The emissions of heavy metals into the air can be reduced by, for instance, taking off a bleed stream and stockpiling the collected dust instead of returning it to the raw feed. However, in each case these considerations should be weighed against the consequences of releasing the heavy metals into the waste stockpile. Another possibility is the hot-meal bypass, where calcined hot-meal is in part discharged right in front of the kiln entrance and fed to the cement preparation plant. Alternatively, the dust can be added to the clinker. Another important measure is a very well controlled steady operation of the kiln in order to avoid emergency shut-offs of the electrostatic precipitators. These may be caused by excessive CO concentrations. It is important to avoid high peaks of heavy metal emissions in the event of such an emergency shut-off.

53. The most relevant emission reduction measures are outlined in table 8. To reduce direct dust emissions from crushers, mills, and dryers, fabric filters are mainly used, whereas kiln and clinker cooler waste gases are controlled by electrostatic precipitators. With ESP, dust can be reduced to concentrations below 50 mg/m<sup>3</sup>. When FF are used, the clean gas dust content can be reduced to 10 mg/m<sup>3</sup>.

Table 8: Emission sources, control measures, reduction efficiencies and costs for the cement industry.

Emission source	Control measure(s)	Reduction efficiency (%)	Abatement costs
Direct emissions from crushers, mills, dryers	FF	Cd, Pb: > 95	..
Direct emissions from rotary kilns,	ESP	Cd, Pb: > 95	..

clinker coolers			
Direct emissions from rotary kilns	Carbon adsorption	Hg: > 95	..

Glass industry (annex II, category 8)

54. In the glass industry, lead emissions are particularly relevant given the various types of glass in which lead is introduced as raw material (e.g. crystal glass, cathode ray tubes). In the case of soda-lime container glass, lead emissions depend on the quality of the recycled glass used in the process. The lead content in dusts from crystal glass melting is usually about 20-60%.

55. Dust emissions stem mainly from batch mixing, furnaces, diffuse leakages from furnace openings, and finishing and blasting of glass products. They depend notably on the type of fuel used, the furnace type and the type of glass produced. Oxy-fuel burners can reduce waste gas volume and flue dust production by 60%. The lead emissions from electrical heating are considerably lower than from oil/gas-firing.

56. The batch is melted in continuous tanks, day tanks or crucibles. During the melting cycle using discontinuous furnaces, the dust emission varies greatly. The dust emissions from crystal glass tanks (<5 kg/Mg melted glass) are higher than from other tanks (<1 kg/Mg melted soda and potash glass).

57. Some measures to reduce direct metal-containing dust emissions are: pelleting the glass batch, changing the heating system from oil/gas-firing to electrical heating, charging a larger share of glass returns in the batch, and applying a better selection of raw materials (size distribution) and recycled glass (avoiding lead-containing fractions). Exhaust gases can be cleaned in fabric filters, reducing the emissions below 10 mg/m<sup>3</sup>. With electrostatic precipitators 30 mg/m<sup>3</sup> is achieved. The corresponding emission reduction efficiencies are given in table 9.

58. The development of crystal glass without lead compounds is in progress.

Table 9: Emission sources, control measures, dust reduction efficiencies and costs for the glass industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs)
Direct emissions	FF	> 98	..
	ESP	> 90	..

Chlor-alkali industry (annex II, category 9)

59. In the chlor-alkali industry,  $\text{Cl}_2$ , alkali hydroxides and hydrogen are produced through electrolysis of a salt solution. Commonly used in existing plants are the mercury process and the diaphragm process, both of which need the introduction of good practices to avoid environmental problems. The membrane process results in no direct mercury emissions. Moreover, it shows a lower electrolytic energy and higher heat demand for alkali hydroxide concentration (the global energy balance resulting in a slight advantage for membrane cell technology in the range of 10 to 15%) and a more compact cell operation. It is, therefore, considered as the preferred option for new plants. Decision 90/3 of 14 June 1990 of the Commission for the Prevention of Marine Pollution from Land-based Sources (PARCOM) recommends that existing mercury cell chlor-alkali plants should be phased out as soon as practicable with the objective of phasing them out completely by 2010.

60. The specific investment for replacing mercury cells by the membrane process is reported to be in the region of US\$ 700-1000/Mg  $\text{Cl}_2$  capacity. Although additional costs may result from, *inter alia*, higher utility costs and brine purification cost, the operating cost will in most cases decrease. This is due to savings mainly from lower energy consumption, and lower wastewater treatment and waste-disposal costs.

61. The sources of mercury emissions into the environment in the mercury process are: cell room ventilation; process exhausts; products, particularly hydrogen; and waste water. With regard to emissions into air, Hg diffusely emitted from the cells to the cell room are particularly relevant. Preventive measures and control are of great importance and should be prioritized according to the relative importance of each source at a particular installation. In any case specific control measures are required when mercury is recovered from sludges resulting from the process.

62. The following measures can be taken to reduce emissions from existing mercury process plants:

- Process control and technical measures to optimize cell operation, maintenance and more efficient working methods;
- Coverings, sealings and controlled bleeding-off by suction;
- Cleaning of cell rooms and measures that make it easier to keep them clean; and
- Cleaning of limited gas streams (certain contaminated air streams and hydrogen gas).

63. These measures can cut mercury emissions to values well below 2.0 g/Mg of  $\text{Cl}_2$  production capacity, expressed as an annual average. There are

examples of plants that achieve emissions well below 1.0 g/Mg of  $\text{Cl}_2$  production capacity. As a result of PARCOM decision 90/3, existing mercury-based chlor-alkali plants were required to meet the level of 2 g of Hg/Mg of  $\text{Cl}_2$  by 31 December 1996 for emissions covered by the Convention for the Prevention of Marine Pollution from Land-based Sources. Since emissions depend to a large extent on good operating practices, the average should depend on and include maintenance periods of one year or less.

Municipal, medical and hazardous waste incineration (annex II, categories 10 and 11)

64. Emissions of cadmium, lead and mercury result from the incineration of municipal, medical and hazardous waste. Mercury, a substantial part of cadmium and minor parts of lead are volatilized in the process. Particular actions should be taken both before and after incineration to reduce these emissions.

65. The best available technology for dedusting is considered to be fabric filters in combination with dry or wet methods for controlling volatiles. Electrostatic precipitators in combination with wet systems can also be designed to reach low dust emissions, but they offer fewer opportunities than fabric filters especially with pre-coating for adsorption of volatile pollutants.

66. When BAT is used for cleaning the flue gases, the concentration of dust will be reduced to a range of 10 to 20  $\text{mg}/\text{m}^3$ ; in practice lower concentrations are reached, and in some cases concentrations of less than 1  $\text{mg}/\text{m}^3$  have been reported. The concentration of mercury can be reduced to a range of 0.05 to 0.10  $\text{mg}/\text{m}^3$  (normalized to 11%  $\text{O}_2$ ).

67. The most relevant secondary emission reduction measures are outlined in table 10. It is difficult to provide generally valid data because the relative costs in US\$/tonne depend on a particularly wide range of site-specific variables, such as waste composition.

68. Heavy metals are found in all fractions of the municipal waste stream (e.g. products, paper, organic materials). Therefore, by reducing the quantity of municipal waste that is incinerated, heavy metal emissions can be reduced. This can be accomplished through various waste management strategies, including recycling programmes and the composting of organic materials. In addition, some UN/ECE countries allow municipal waste to be landfilled. In a properly managed landfill, emissions of cadmium and lead are eliminated and mercury emissions may be lower than with incineration. Research on emissions of mercury from landfills is taking place in several UN/ECE countries.

Table 10: Emission sources, control measures, reduction efficiencies and costs for municipal, medical and hazardous waste incineration

Emission source	Control measure(s)	Reduction efficiency (%)	Abatement costs (total costs US\$)
Stack gases	High-efficiency scrubbers	Pb, Cd: > 98; Hg: ca. 50	..
	ESP (3 fields)	Pb, Cd; 80 - 90	10-20/Mg waste
	Wet ESP (1 field)	Pb, Cd: 95 - 99	..
	Fabric filters	Pb, Cd: 95 - 99	15-30/Mg waste
	Carbon injection + FF	Hg: > 85	operating costs: ca. 2-3/Mg waste
	Carbon bed filtration	Hg: > 99	operating costs: ca. 50/Mg waste